Stratigraphical study on the pyroclastic flow deposits including a Middle Pleistocene marker tephra of Shiobara-Otawara (So-OT) tephra, the southern Northeast Japan: Recognition of So-OT with major and trace elements of glass shards

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[3]F gr ctvo gpv'qh'Pcwtcn'j kuvqt{"uekgpegu."J qmmdkf q"Wpkxgtukv{."Uctrqtq."J qmmdkf q. [4]F gr ctvo gpv'qh'I gqi ctrj {."Vqm{q"
O gvtqrqnkcp"Wpkxgtukv{."O kpco kqucy c."J cej kqik'Vqm{q."Lcr cp=[6]TNCJ C."Wpkxgtukv{'qh'Qzhqtf."Qzhqtf."WM='
[6]F gr ctvo gpv'qh'I gqnqi {."Vtkpkv{"Eqnigig'F wdrkp='

Introduction

Uj kqdctc/Qvcy ctc"r {qencuvke"hnqy "*Uq/QV='Uw| wmk'gv'cn04226+'ku"c"nctig/uecng"r {qencuvke"hnqy "htqo "Uj kqdctc/Ecnfgtc."yj g"pqtyj gtp"Mcpvq"ctgc."egpvtcn'Lcr cp0.Uq/QV'ccceo r cpkgf "c"fcn/qu'vgr tc."y j kej "j cu"dggp"kfgpvkfkgf "kp"E; 223E"ugf ko gpvct{"ugsw gpeg."ohh'Uj ko qokxc"*722'o "PP G"htqo "y j g'uqwec+'pqtyj gtp"Lcr cp."d{ "F IX'Ej km{w"*Uw| wmk'gv'cn04234+0J qy gxgt."yj gtg"ctg"uqo g"qh'ci g"o qf gm"kp"E; 223E"cuuqekcvgf "y kyj "yj g"ci g"qh'Uq/QV0.F go ku'qu'gv'cn0'*4233+'kpf kccvkf "yj cv'yj g"ci g"qh'Uq/QV"kp"E; 223E"eqtg"ku"472'mc." dgecwug'yj g"ci g"ku"gurko cvgf "d{"ci gu'qh'uqo g"y kf g"urtgcf "vgrj tcu'cpf "uqo g"mkpf "qh'dkq/uvtcvki tcrj kecn'f cvc0. Qp"yj g"qyj gt"j cpf ."O cuwo wtc"gv'cn0'*4239+'uj qy gf "yj cv'yj g"ci g"qh'Uq/QV"ku'497'mc'kp"E; 223E"eqtg"y kj " uqo g"qh'yj g'vgrj tc"ci gu'cpf "dkquvtcvki tcrj {"ci gu'*Fqo ku'qu'gv'cn04233+0

Tgegpvn{ ."[co cf c"gv'cn0'*kp"r tguu+'ggzco kpgf "yj g'vgrj tqurtcvki tcrj {"ctqwpf "yj g'r tqzko cn'ctgc"qh'Uq/QV cpf "tgr qtvgf "Uj kqdctc/Mctvo cvc"*Uq/MV+'cpf "Uj kqdctc/Vcpqj ctc"*Uq/VP +'r {qencuvke"hnqy "f gr quku'htqo "qnf guv'vq "{qwpi gt'wpf gt'Uq/QV0.Vj g"uvtcvki tcrj {"qh'yj gug"r {qencuvke"f gr qukus."kpvgi tcvgf "y kyj "qyj gt" ko r qtvcpv'vgrj tc"wpkvu."ctg'tgeqpuvtwevgf "kpvq"yj g"hqmny kpi "tgncvkxg'uvtcvki tcrj ke'qtf gt<"C3Ro "qt"C4Ro ."Uq/MV."C6Ro ."Uq/VP ."Uq/QV."C| /O kR."DV87'htqo "{qwpi guv'vq"qnf guv'*[co cf c"gv'cn0'kp"r tguu+0.Cnuq."yj g"ci gu" qh'Uq/MV."cpf "Uq/VP "y gtg"guvtkevgf "y kyj "C| /O kR'*522'Ö'50'mc+'cpf "j ki j /tguqnwkqp"vgrj tc"ci gu"kp" r ctvkewnct"DV87'*497'mc+."C6Ro "*559'mc+'cpf "C3Ro "*5:2/632'mc+0

J qy gxgt." Uq/MV." Uq/VP " cpf " Uq/QV" y gtg" f kuvkpi wkuj gf "qpn{ "d{ "yj kgt" j gcx{ "cpf "nki j v" o kpgtcn' eqo r qukvkqp."tghtcevkxg"kpf kegu"qh'qtyj qr {qzgpgu"cpf "o clqt"gngo gpv'qh'i ncuu"uj ctf u0.Vj ku'uvwf {"f kuewuugu" yj g"f khhgtgpegu"co qpi "Uq/VM."Uq/VP "cpf "Uq/QV"y kj "yj gkt"eqo r qukvkqp'qh'ngy "o clqt'gngo gpv'f cvc"qh'i ncuu" uj ctf u"y kyj "c"f khhgtgpv'o cej kpg"cpf "vtceg"gngo gpvu"qh'i ncuu"uj ctf u0.Cnuq ."yj ku'tgugctej "eqo r ctgu"yj g"vtceg" gngo gpv'y kyj "yj g"qyj gt'Lcr cpgug"vgrj tcu0

Analysis

O clqt"cpf "o kpqt"gngo gpv'xqncecke'i ncuu'ej go kuvt{"qh'kpf kxkf wcn'qluvexgpkng"encuu'y cu'f gvgto kpgf "wukpi "c" y cvgngpi yj /f kur gtukxg'LGQN": 822'gngevtqp"o kctqr tqdg"kp"yj g'Tgugctej "Ncdqtcvqt{"hqt"Ctej cgqnqi {"cpf "yj g" J kuvqt{"qh'Ctv."Wpkxgtukv{"qh'Qzhqtf0.Vj g"cpcn{ugu'y gtg"r gthqro gf "wukpi "c"Vj go q"Uekgpvkflke'KECR'S e'KECR/O U"eqwr ngf "vq"c"Vgf f{pg"Rj qvqp"O cej kpi0Cpcn{vg'I 4'3; 5'po "gzko gt"ncugt'cdncvkqp'u{uvgo "y kyj "c"J gnGz" KKVy q/xqnwo g"cdncvkqp"egmn'cv'yj g"F gr ctvo gpv'qh'I gqnqi {."Vtkpkv{"Eqnigig."F wdrkp0

Characteristic properties of each units of So-KT, So-TN and So-OT

Uq/QV'ku'tqwi j n{ "f kxkf gf "kpvq"ogy gt"cpf "wr r gt'r ctvu0.Vj g"ogy gt'r ctv'ku'eqpukuvgf "qh'yj g'wo keg'hcm'f gr qukv' *Uq/QV'r hc+'cpf "uwti g"f gr qukv'*Uq/QV'uwti g+0.Vj g"wr r gr 'r ctv'ku'eqpukuvgf "qh'yj g"yj gg"r {qencuvke"hnqy " f gr quku0.Vj gug"r {qencuvke"hnqy "f gr quku"ctg"f kxkf gf "kpvq"r wo keg'hnqy "f gr qukv'*Uq/QV'r hf/n+."r wo keg'hnqy " f gr qukv'*Uq/QV'r hf/o +."cpf "ueqtkc'hnqy "f gr qukv'*Uq/QV'r hf/w0'Uq/VP "ku"eqo r qugf "y kyj "Wpkv/c/f "htqo " qnf guv'vq "{qwpi guv0'*[co cf c"gv'cn0'kp"r tguu+0Wpkvu."c."e"cpf "f "ctg'r wo keg'hnqy "f gr qukus'cpf "wpkv'd"ku"ueqtkc" hnqy "f gr quku0.Uq/MV"ku"c"r wo keg'hnqy "f gr qukv0

Trace and major element of glass shards from So-KT and each unit of So-TN and So-OT

Vj g"pgy "f cvc"qh'yj g"o clqt"gngo gpv'kp"yj ku'tgugctej "uj qy u"c"uko knct'r cwgtp"vq"[co cf c"gv'cn0'*kp"r tguu+'hqt" Uq/MV'cpf "cm'wpkvu'qh'Uq/VP "cpf "Uq/QV0

Kp"yj g"pgy "f cvc"qp"yj g"o clqt"gngo gpv."Uq/MV'cpf "yj g"qyj gt"eqwr ng'qh'vgrj tcu"ctg"engctn{"f kuvkpi wkuj gf " htqo "EcQ'cpf "M4Q0.Uq/MV'j cu'EcQ/tkej "*30 ó42'y v0 +'cpf "M4Q/r qqt"*405ó405'y v0 +'i ncuu'uj ctf u'yj cp'Uq/ VP "cpf "Uq/QV0.Cnuq."Uq/QV'cpf "Uq/VP "ctg"f kxkf gf "htqo "Cn4Q5'cpf "HgQ0'Uq/QV'j cu'Cn4Q5/tkej "*kQg0'Uq/ QV"uwti g<340ó34Q +'cpf "HgQ/r qqt"*kQ0'Uq/QV'r hf/n+."30 ó4403"y v0 +'i ncuu'uj ctf u'eqo r ctgf "vq "Uq/VP 0' Vj g"o clqt"gngo gpv'qh'Uq/QV'r hc"ku'uko knct"vq "Uq/QV'r hf/n'cpf "Uq/QV'r hf/o 0'Uq/QV'uwti g'j cu'Pc4Q/tkej " *50 ó4Q5"y v0 +'cpf "nkwg/M4Q/r qqt"*405ó405'y v0 +'i ncuu'uj ctf u'cpf "Uq/QV'r hf/w'j cu'M4Q'cpf "HgQ/tkej " *M4Q<405ó405'y v0 ='HgQ<30 ó4Q3'y v0 +'cpf "Pc4Q/r qqt"*503ó505'y v0 +'i ncuu'uj ctf u'eqo r ctgf "vq "yj g"qyj gt" wpkvu'qh'Uq/QV0

Vj ku"tgugctej "cpcn{| gf "vtceg"gngo gpv"qh"i ncuu"uj ctfu"htqo "Uq/MV."cm"wpkku"qh"Uq/VP "cpf "Uq/QV."cmj qwi j "yj g"fcvc"qh"Uq/VP "e"y cu"gzcnwfgf "fwg"vq"cdpqto cnkv{"qh"yj g"fcvc"qh"Uq/VP "e"*Hki 0 3+0 Vj ug"vtceg"gngo gpv"fcvc"kpfkecvg"yj g"engce "fkhhgtgpeg"dgvy ggp"Uq/MV"cpf "yj g"qyj gt"eqwrng"qh"vgrj ctu "*Hki 0 Uq/MV "ku"fkuvkpi wkuj gf "htqo "Uq/VP "cpf "Uq/QV"y kyj "o qut"qh"kpeqo rcvkdng"gngo gpvu"y kyj qw."Ut."kp "rctvkewnct"J TGG "*Iq0 "5"Õ'3"[d+"cpf "["*42"Õ'3"r ro +"*Hki 0 3+0 Cmj qwi j "yj g"vtceg"gngo gpv"y cupøv"cdng"vq "fkuvkpi wkuj "dgvy ggp "Uq/VP "cpf "Uq/QV. "cpf "cm"wpkku"qh"Uq/VP "cpf "Uq/QV"*Hki 0 Vj g"vtceg"gngo gpv"qh"cm"wpkku"qh"Uq/VP "cpf "Uq/QV"y gtg"gptkej gf "kp "NTGG "tgncvkxg"vq "yj g"J TGG "*Nc[d" ?"7"Õ'3+0 Vj g"vtceg"gngo gpv"eqpegpvtcvkqpu "qdugtxgf "kp "yj g"i ncuugu"uj qy gf "uqo g"uki pkhkecpv"xctkcdknkv{ "*Iq0 "Uq/QV"r he<"7296977"r ro "Dc+"y j knvt"yj g"qyj gt"kpeqo rcvkdng"vtceg"gngo gpv"eqpegpvtcvkqpu"ctg"j qo qi gpgqwu"*Iq0 "Uq/VP "d<65"Õ'6"r ro "[+0"

Vj g"vtceg"gngo gpv"qh"Uq/VP "cpf "Uq/QV"gptkej gf "kp "NTGG "tgncvkxg"vq "yj g"J TGG "*Iq0 "Uq/QV"r hf/o <"Nc[d" ?"7"Õ'3+0 Vj g"vtceg"gngo gpv" eqpegpvtcvkqpu" qdugtxgf " kp "yj g" i ncuugu"uj qy gf "uqo g"uki pkhkecpv"xctkcdknkv{ " *Iq0" Uq/QV" r hn/r hc<"7296977" r ro " Dc+." y j knvt" yj g" qyj gt" kpeqo rcvkdng" vtceg" gngo gpv"eqpegpvtcvkqpu"ctg"j qo qi gpgqwu"*Iq0"Uq/QV"r hf/o <5;"Õ'5"r ro "[+0"

Comparison chemical compositions of So-KT, So-TN and So-OT with other Japanese tephras

Cqmk"cpf "O cej kfc "*4228+"cpcn{| gf "o clqt"gngo gpv"eqo rqukkqpu"qh"y kfgurtgcf "vgrj tcu"gtwrvgf "htqo "xctkqwu"uqwtegu"kp "Lcr cp0 Cnuq. "yj g"tugctej "eqpvgpfgf "vgrj tcu"htqo "P qtyj gcuv"Lcr cp"cte"j cxkg"M₄Q/r qqt "*cr r tqzko cvgn{ "/5"y v0 +"xqrecpkg"i ncuu. "cpf "vgrj tcu"htqo "Uqwyj y gut"Lcr cp"cte"j cxkg"M₄Q/tkej "*5/"y v0 +"xqrecpkg"i ncuu0 Vj g"xcnwg"qh"M₄Q"qh"Uq/MV. "Uq/VP "cpf "Uq/QV"eqo g"wpfgt"vgrj tcu"htqo "P qtyj gcuv"Lcr cp"cte0 *Mko wtc"gv"cn0 *4237+"cpf "O ctw{co a"gv"cn0 *4238+"cpcn{| gf "yj g"mpqy p"vtceg"gngo gpv"eqo rqukkqpu"qh"vgrj tc"wpku"yj cv"gtwrvgf "htqo "uqwyj gte"M{wuj w."pqtyj gte"J qpuj w"cpf "yj g"P qtkmwtc"xqrecpkg"| qpg0 Cnuq. "O kk"vnq "*4223+"tgr qtvgf "yj cv"Nc["ku"ko r qtvcpv"fkci pqukke"vqqn"hqt"cuuki pkpi "vgrj tc"nc{gt"kp "Lcr cp"cpf "yj g"xcnwg"qh"Nc["kp "P qtyj gcuv"Lcr cp"cte"y cu"ecrewncvgf "cdqw "2027/2070. Vj g"tguwn"qh"yj g"eqo rctkuqp"vq"yj g"vtceg"gngo gpv"fcvc"htqo "yj g"r tgxkqwu"tugctej gu"kpfkecvg"yj cv"yj g"vtceg"gngo gpv"qh"Uq/MV. "Uq/VP "cpf "Uq/QV"j cu"c"uko knct"vtgpf "vq "P qtyj gcuv"Lcr cp"cte0 Cnuq. "yj g"Nc["qh"Uq/MV"cpf "cm"wpkku"qh"Uq/VP "cpf "Uq/VP "cte"iuwg"j ki j gt"yj cp"207"*Uq/MV<2088. "cm"wpkku"qh"Uq/VP "cpf "Uq/QV<2072/2076+0"
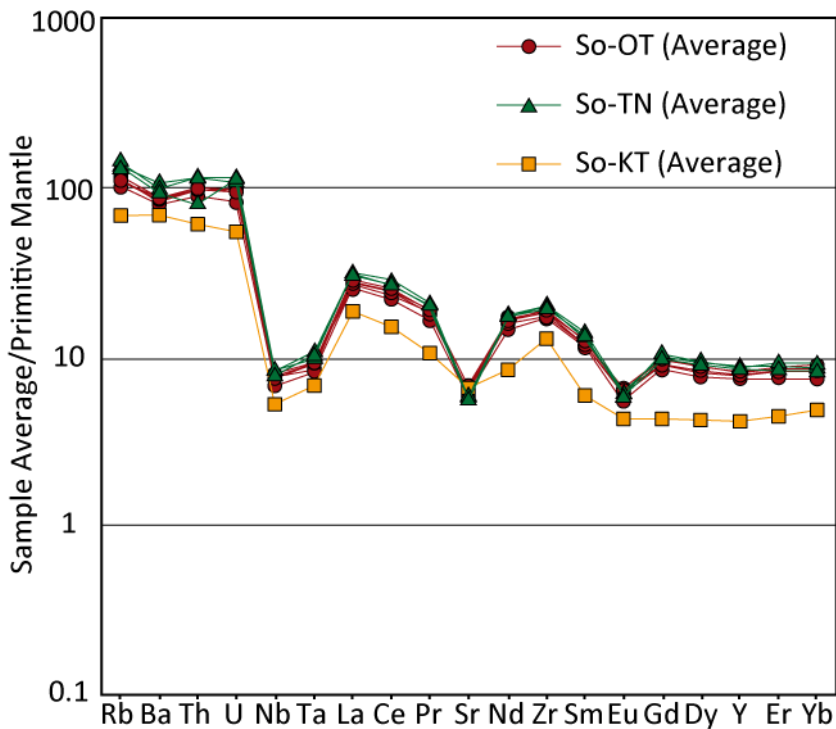

Fig. 1. Trace element of the average values of volcanic glass shards of So-KT, So-TN and So-OT.

References

Cqmk"M0 cpf "O cej kfc. "J 0 "O clqt"gngo gpv"eqo rqukkqp "qh"xqrecpkg"i ncuu"uj ctfu"kp "yj g"ncvg"S wcvgtpctk{ "y kfgurtgcf "vgrj tcu"kp "Lcr cp"/F kuvtkdwkqp "qh"vgrj tc"wukpi "M₄Q/VkQ₄"fkci tco u"1l"Dwm0 G qp0 Uwtx0 "Lcr cp "4228. "79. "43; /47: 0"

"

F qo kuw."J 0"P kuj k "J 0"Wej kf c."L0"Qf c."O 0"Qi cpg."M0"Vcktc."C0"Cqkmg."M0"cpf "Uj ko qmkc"O ketqhquukn'
Tgugctej "I tqwr ."Ci g"o qf gn'qh'eqtg"ugf ko gpvu"vcmgp"d{ "F IX"EJ KM[W'fwtkpi "yj g"uj cmgf qy p"etwkugu"
qhh'Uj ko qmkc"Rgpkpuwnc"11'P gy ugt{w0'Uvtcki r t04233.'66.'335/3440'

Mko wtc."L0"P ci cj cuj k"[0"Ucvqi wej k"[0"cpf "Ej cpi ."S 0"Qtki kpu'qh'hgmuke"o ci o cu"kp"Lcp cpgug"uwdf wevkqp'
| qpg<'I gejgo kecn'ej ctcevgtk| cvkqpu"qh"vgr tc "htqo "ecnf gtc/hqto kpi "gtwr vkqpu">"7"O c0'11'I gejgo 0'
I gqr j {u0'I gqu{u0'4237.'38.'4369/43960'

O ctw{co c."U0"J cwqtk"M0'J ktcvc."V0'cpf "F cpj ctc0'V0'C'r tqr qugf "o gyj qf qmq i {"hqt"cpcn{ugu'qh'y kf g/tcpi gf "
gn go gpvu"kp'xqrecnkpi 'i rcuu'uj ctfu'kp'y kf gur tgcf "S wcvgtpct{"vgr j tcu"11'S cv0'Kpv04238.'5; 9.'489/4: 20'

O cutw{øwtc." V0" Hwtwucy c." C0" Uj ko qi co a." M0" I qvq." N 0' cpf " Mko cuwdctc." L0" Ncvg" swcvgtpct{"
vgr j tqutcvki tcr j {"cpf "et{r vqvgr j tqutcvki tcr j {"qh'f ggr /ugc"ugs wgpege"*Ej km{w'E; 223E"eqtgu+'cu'vqqnu'
hqt'o ctkpg'vgttceg'ej tqpqnqi {"kp'P G'Lcr cp"11'S cv0'I gqej tqpqr04239.'62.'34; /3670'

O k{ wpq."M0"Kpxgguvki cvkqp"qh'xqrecpke"ctgcu"cpf "yj g"kphnwgpee"uecng"qh'yj e'xqrecpke"ctgcu"y kyj "yj g"Rnkqegpg'
cpf "Rngkuvqegpe"y kf gur tgcf "vgr j tcu"11'Ej km{ w'O qpyj n{'4223.'45.827/82; 0'

Uw| wnk"V0"Hwlky ctc."Q0'cpf "F cpj ctc."V0"Uvtcvki tcr j {"cpf "ej tqpqnqi {"qh'o kf f ng'Rngkuvqegpe"vgr j tcu"kp'cpf "
ctqwpf 'Ck{ w'ctgc."nqtyj gcu'Lcr cp"11'Lqwr0'Vqm{q'I gqi r0'Uee04226.'335.'83/35: 0'

Uw| wnk'V0"Cqmk"M0"Mcy ck'V0"Ucmam qvq."V0'cpf "Kkko c."M0'O kf f ng"Rngkuvqegpe"vgr j tqutcvki tcr j {"qh'
E; 223"eqtg "f tkmgf "d{"EJ KM[W'qhh"Uj ko qmkc"Rgpkpuwrc"cpf "ku'cr r nkecvkqp'hqt'kp 11'Lcr cp'I gqekQ'
Wpkqp'O ggv04234.'H S T45/360'

[co cf c."O 0"Mcy ck'V0"P kuj k{ cy c"H0'cpf "Uw| wnk"V0"Uvtcvki tcr j kecn'uuwf {"qp"yj e"O kf f ng"Rngkuvqegpe'
r {tqenxunke"hmqy "f gr quku."nqtyj gtp"Vqej ki k'cpf "uqwyj gtn"Hwmwuj ko a'Rtghgewtgu."P qtyj gcu'Lcr cp"11'Lqwr'
I gqn0'Ueq0'Lcr cp'kp'r tguu0'

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